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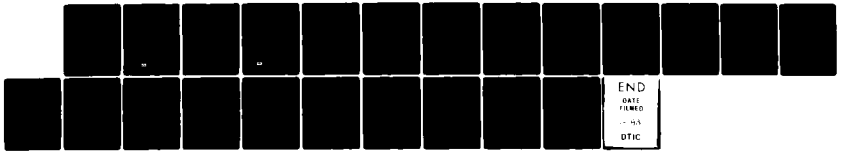

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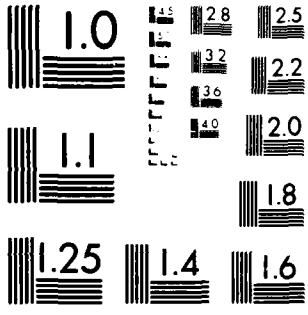

PROFESSIONAL PAPER 358 / September 1982

EVALUATING TACTICAL COMMAND AND CONTROL SYSTEMS—A THREE-TIERED APPROACH

George Akst

CNA CENTER FOR NAVAL ANALYSES

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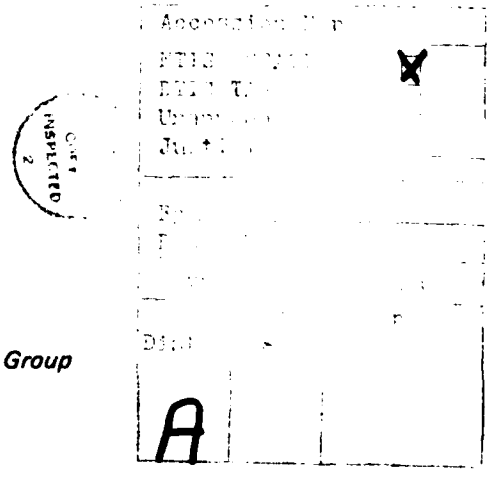

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ABSTRACT

The United States Marine Corps is developing a Command and Control system called the Tactical Combat Operations (TCO) system as part of a larger command and control architecture. This analysis was designed to assist the Marine Corps in deciding whether or not to continue development of TCO.

We identified seven alternatives to TCO, which included variants of TCO, non-Marine systems and the current manual system. We first examined the costs of the alternatives. Next, we analyzed the effectiveness at three different levels. The first level looked at performance. The next level examined how improved performance assists in forming perceptions, which in turn are used to allocate resources. The final level focused on overall battle outcome. In order to compare all alternatives fairly, we constructed equal-cost forces by augmenting the less expensive alternatives with additional tank battalions. These forces were then compared using a computerized model.

At all three levels of effectiveness, automating the command and control process was advantageous. The value of certain decision aids proved to be relatively high whereas the value of automation to lower echelons was relatively low.

INTRODUCTION

Today's battlefields are becoming more and more complex because of the influx of advanced electronic systems. The number of sensors that provide more timely and accurate information about enemy forces is increasing. Also, enemy forces are becoming more sophisticated. The improved electronic systems coupled with the sophisticated forces increase the information available to the modern day commander. All this places an enormous burden on the command and control structure.

Command and control (C^2) is a term that is widely used but perhaps little understood. According to JCS Pub 1, command and control is "the exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of his mission." In interpreting this definition, we must realize that a command and control system is simply a tool the decisionmaker uses, not an end in itself. In other words, a command and control system is a collection of equipment, personnel, and procedures that helps the decisionmaker gather, process, and disseminate information. The increasing amount of information available to the commander generates a generally accepted need to include selective automation as part of the command and control system. The big questions decisionmakers face are: How much automation is necessary? How should it be implemented?

In response to their growing command, control, and communications (C^3) requirement, the United States Marine Corps initiated the Marine Corps Tactical Command and Control System (MTACCS) in 1966. MTACCS consists of seven distinct, but closely related, systems designed to improve the Marine Corps' C^3 processes. At the core of MTACCS is the Tactical Combat Operations (TCO) system. It is the focal point for operational information within the Marine Air-Ground Task Force (MAGTF). TCO is the tactical data system that will provide assistance to the operations and intelligence staff from MAGTF headquarters down to infantry battalion and aircraft squadron operations centers.

TCO is designed to simplify handling data, which includes input, storage, retrieval, and processing. This will be accomplished using a sophisticated suite of data processing equipment, which includes microcomputers, screens that can display graphics, printers, and storage devices. The software will facilitate the production and dissemination of reports and provide several decision aids to assist the commander and his staff. These will be described in more detail later in the paper.

TCO will use the same hardware as another MTACC system: the Marine Integrated Fire and Air Support System (MIFASS). Consequently, although TCO is only in the advanced development phase, the hardware is now being built under the engineering development contract for MIFASS. Based on the progress to date, the Marine Corps Operations Analysis Group of the Center for Naval Analyses was asked to analyze the cost and

effectiveness of TCO. The purpose of the analysis was to help the Marine Corps decide whether to continue developing TCO as currently designed, to suggest altering that design in some systematic manner, or to recommend pursuing development of an entirely different system.

ALTERNATIVES EXAMINED

The first step in our analysis was to identify possible alternatives to TCO. We examined seven, which included variants of TCO as well as non-Marine Corps systems. For the non-Marine Corps systems, the alternatives consisted of a ground (Army) system coupled with an air (Air Force) system. In this paper we compare the following alternatives:

- Full TCO--This is the version of TCO currently being developed; it is described in the system description document for TCO
- Nodally Austere TCO--This version of TCO eliminates all centers at infantry battalions and air squadrons.
- Functionally Austere TCO--This version eliminates all decision aids and the large screen display planned for the higher echelons.
- Very Austere TCO--This version of TCO basically eliminates those features that were deleted in the other two austere variants.
- Wavell plus Computer Assisted Force Management System (CAFMS)--Wavell is the automated C^2 system used in the operations section in the British Army. A prototype has been in the field with the I British Corps in Germany since 1978. The U.S. Air Force is developing CAFMS primarily to assist in the construction and dissemination of the air tasking order.
- Maneuver Control System (MCS) plus CAFMS--MCS is the planning and operations C^2 system the U.S. Army is developing. The system is being implemented in stages, with the first stage deployed to the VII Corps in Europe in September 1980. This will be coupled with the Air Forces's CAFMS.
- Manual System--This is the current system the Marine Corps uses. Much of the information is maintained on file cards, status boards, and acetate covered maps.

LIFE-CYCLE COST ANALYSIS

We estimated life-cycle costs for TCO variants and the alternatives (table 1). These costs reflect 10 years of operation.

TABLE 1

INCREMENTAL LIFE-CYCLE COSTS

ALTERNATIVE	COST (MILLIONS OF FY 1982 DOLLARS)
TCO	680
FUNCTIONALLY AUSTERE TCO	560
NODALLY AUSTERE TCO	450
VERY AUSTERE TCO	340
WAVELL/CAFMS	310
MCS/CAFMS	280
MANUAL	0

Only costs that are mariginal with respect to the manual baseline are included. Also included are costs for extra training requirements plus the cost of additional personnel needed for a system. The costs of existing personnel and sunk costs are excluded.

Notice the difference in costs between the functionally austere and nodally austere variants of TCO. The cost of equipping battalions and squadrons with TCO equipment is approximately twice that of developing the decision aids and large screen display. We shall further examine this disparity in the discussion of the effectiveness analysis.

METHODOLOGY

Our methodology analyzed the effectiveness of the alternatives at three different levels, or tiers. At the first tier, we examined the performance of the individual systems and were able to quantify several timeliness and accuracy parameters as well as the value of the decision aids. At the second tier, we studied how the differences in performance would affect the commander's and staff's ability to make decisions. In this portion of the analysis, we looked at the ability to make plans and allocate resources. Finally, in the third tier of effectiveness we explored the value of improved decision making in winning the battle.

In the remainder of this paper, we discuss each of the three levels of effectiveness in detail, describing the results at each level. Due to the lack of data available for the non-Marine Corps systems, we

assumed the effectiveness parameters for those systems were equal to those for the very austere variant of TCO.

Performance Data

We examined three different classes of performance data: timeliness, accuracy, and improvements due to decision aids. These data were generated from a variety of different sources. The predominant source was system simulations performed at the Marine Corps Tactical System Support Activity. We also analyzed tests of existing systems that performed functions similar to those planned for TCO. Finally, we examined several user evaluations.

Timeliness

The time delay parameter represents time that elapses between the first occurrence of an event and when information on it is processed and friendly forces take action. The time delays resulting from the collection and processing of information on enemy forces are shown in figure 1. Notice that the time delays decrease as the degree of automation increases. In particular, there is a significant difference between the manual and automated systems.

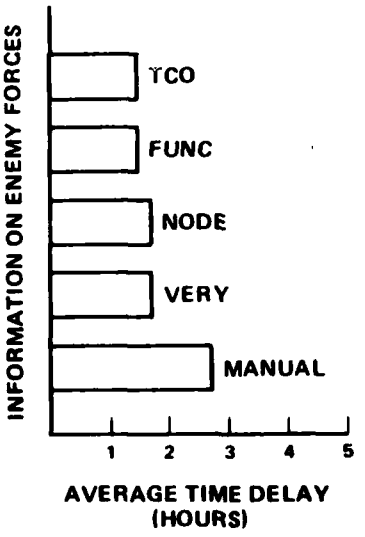

FIG. 1: TIME DELAYS

Accuracy

The accuracy parameter represents the degree of correctness of the information in the command and control system. The error rates for the various alternatives are shown in figure 2. Again, we see a significant difference between the manual and automated systems, while in this case there is no difference among the individual automated systems.

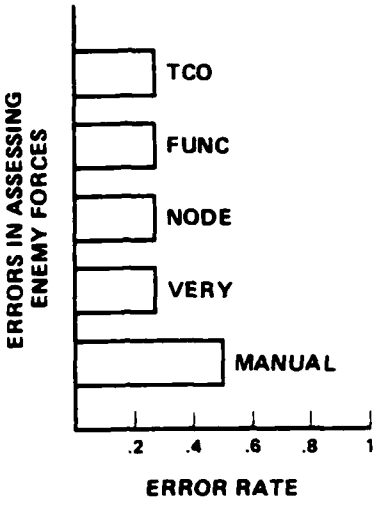

FIG. 2: ERROR RATES

Improvements Due to Decision Aids

Decision aids are automated algorithms that help the staff make their plans and allocate their resources. The effects of three decision aids are included in our analysis. These are battlefield simulation, air routing, and air weaponeering.

Battlefield simulation is a wargaming capability that enables the staff to test and improve plans before implementing them. The effects of these simulations are reflected by modifying the attrition rates at which one side kills another. By using this decision aid, the relative rate at which the friendly side is killed is reduced 26 percent.

The air routing algorithm not only assists the pilot in choosing the best route, but also helps him employ his electronic warfare countermeasures at the most advantageous time. The result of using this decision aid is a 30 percent reduction in aircraft vulnerability.

The air weaponeering algorithm helps planners match the ordnance with the type of target to be attacked. The effect of using this decision aid is a 74 percent increase in effectiveness of air delivered ordnance on preplanned missions.

Assistance for Decisionmaking

At the second level of effectiveness we examined how improvements in the command and control system help the decisionmaker formulate plans and allocate resources.

We first discuss how the staff forms their perceptions of the battlefield, the equation is shown next:

$$\tilde{N}(t) = (1 - P_D)\,\tilde{N}(t - 1) + P_D\,N(t - t_d)\ ,$$

where:

$\tilde{N}(t)$ = Estimated strength of time t
$N(t)$ = Actual strength at time t
P_D = Probability of detection
t_d = Time delay

Basically, this equation says that the current perception is a function of the previous perception and the "new" information that is becoming available. Due to time delays in the system, that "new" information may, in fact, be hours old. These two factors are weighted so that the higher the confidence in the "new" information, the more reliance on it.

Figure 3 displays the accuracy of these perceptions for two alternative systems: the manual system and full TCO. The dashed line represents the perception of enemy defensive strength. The peaks and valleys of the curves indicate reinforcement and attrition, respectively. Notice how more closely the perceptions match reality when TCO rather than the manual system is used.

These perceptions are then used to allocate resources. One of the allocations made is that of moving rifle squads among the front line battalions and the reserves. The allocation of rifle squads is based on a fixed decision rule, which is a function of the current battlefield situation. Therefore, the more accurate one's perception of the battlefield the more closely he can allocate his forces according to the intended rules. The rifle squad allocations using TCO and the manual systems are shown in figure 4. Due to inaccurate perceptions, the planner using the manual system was unable to properly assign the rifle squads. Using TCO, the assignments were made quite accurately.

Battle Outcome

We have just seen how automated command and control systems perform better than the manual system and assist the commander in the planning and decisionmaking processes. However, these measures of effectiveness are secondary to an assessment of how they affect the overall battle outcome. This is the third and highest level of effectiveness we examine. We looked at a number of different measures of battle outcome,

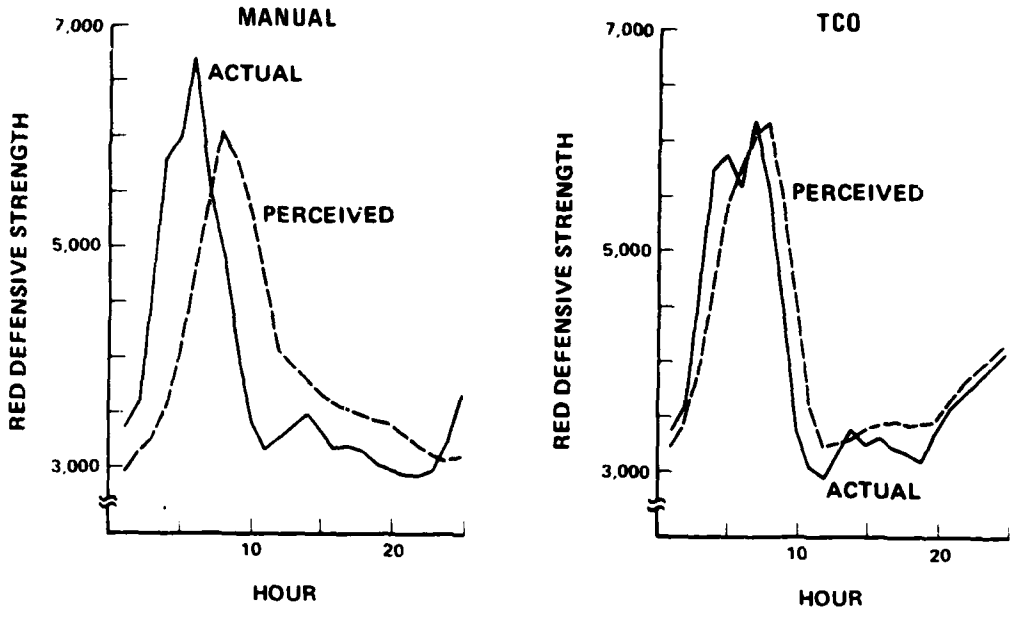

FIG. 3: BLUE'S PERCEPTION OF RED'S DEFENSIVE STRENGTH

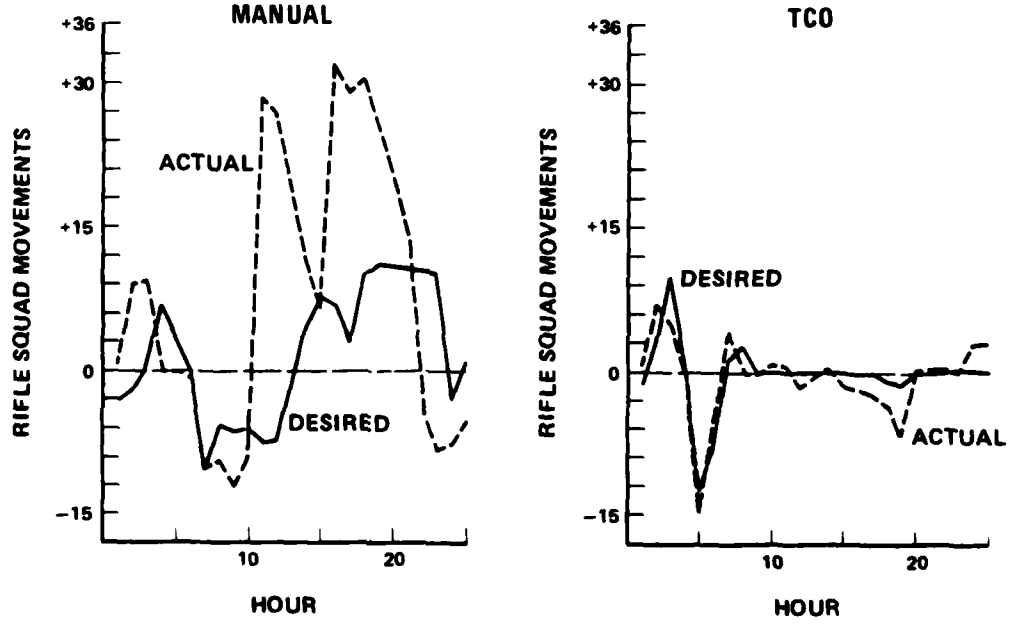

FIG. 4: RIFLE SQUAD ALLOCATIONS

including FEBA movement, fraction of force surviving, and force ratio. For this paper, we focus on the final loss ratio; that is, the ratio of enemy losses to friendly forces after 2 days of battle. For ease of comparison, we present all results in terms of relative loss ratios--values normalized so that the loss ratio of the forces using the manual system is set to 1.00.

To evaluate the battle outcome, we used a deterministic, two-sided computer model known as the C^2 model. This model portrays a large scale amphibious assault incorporating both air and ground battles. The scenario has a Marine Amphibious Force (division-wing team) making an amphibious assault that is opposed by a Soviet force in a Northern European region. We incorporated command and control in the model by keeping track of two battlefield situations: the perceived situation and the true situation. The perceived situation represents the commander's view of the battlefield. This is determined by the intelligence algorithm previously described. This situation is used to make plans, allocate resources, and control the battle. The true situation represents the battlefield as it actually exists. This situation determines the outcome of all combat processes. A flowchart of the model is shown in figure 5.

Using the C^2 model, we calculated the relative loss ratios for forces using the various alternatives. The results are shown in table 2. As one would expect, the greater the degree of automation, the more effective the force. These values also illustrate the relatively higher value that is attributed to using decision aids (nodally austere TCO) compared to that of having equipment at lower echelons (functionally austere TCO).

TABLE 2

LOSS RATIOS FOR FORCES EQUIPPED WITH ALTERNATIVE SYSTEMS

ALTERNATIVE	RELATIVE LOSS RATIO
TCO	1.14
NODALLY AUSTERE TCO	1.11
FUNCTIONALLY AUSTERE TCO	1.04
VERY AUSTERE TCO	1.03
MCS/CAFMS	1.03
WAVELL/CAFMS	1.03
MANUAL	1.00

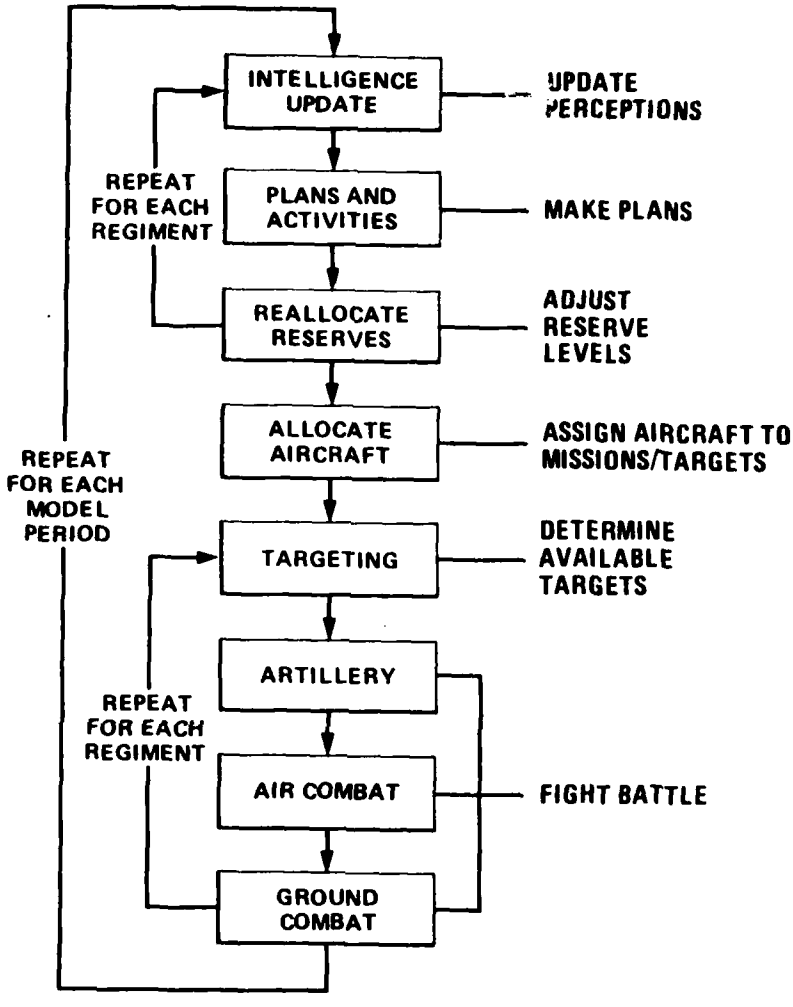

FIG. 5: OVERALL STRUCTURE OF THE C^2 MODEL

Up to this point we have seen that automation helps improve the way the battle is managed. The automated systems perform significantly better then the manual system. This improved performance leads to better perceptions and allocations of resources. Furthermore, all of this contributes to the most important measure: winning the battle. However, these improvements are achieved at a significant increase in cost. To determine whether the improvements justify the cost, we examined the effectiveness of equal-cost forces--forces consisting of C^2 systems and combat elements that have the same total life-cycle costs.

EQUAL-COST ANALYSIS

To evaluate all of the alternatives on a comparable basis, we created equal-cost forces. Using the cost of full TCO as a baseline, we augmented all other alternatives with additional combat forces until their total life-cycle cost equals the baseline. Based on the structure of the C^2 model, we chose to augment the alternatives with additional increments of M-1 tank battalions (a battalion contains 70 tanks). The tank has proven to be a relatively cost-effective weapon in the model and plays a large role in determining overall effectiveness. The structure of the equal-cost forces is shown in figure 6. The number of tanks shown represents the distribution for the entire Marine Corps.

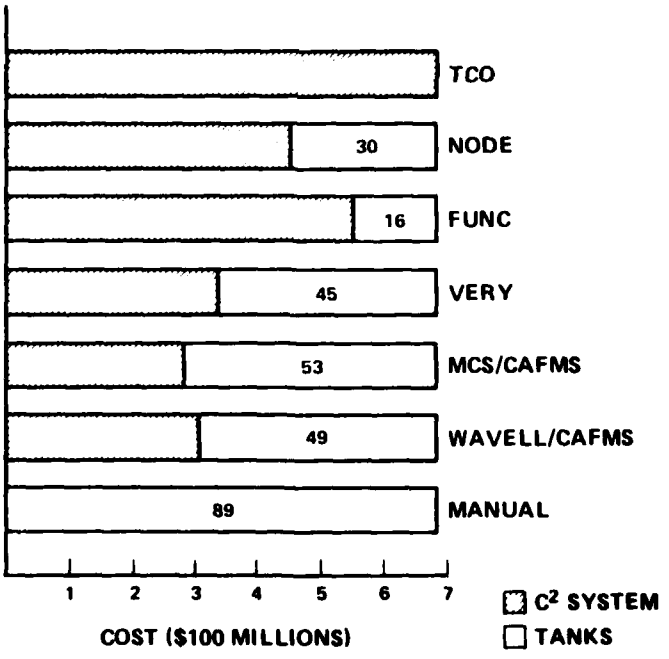

FIG. 6: EQUAL-COST FORCES

We then evaluated these equal-cost forces using the C^2 model. The results are shown in table 3.

TABLE 3

LOSS RATIOS FOR EQUAL-COST FORCES

ALTERNATIVE	RELATIVE LOSS RATIO
NODALLY AUSTERE TCO	1.14
TCO	1.13
MCS/CAFMS	1.07
WAVELL/CAFMS	1.06
VERY AUSTERE TCO	1.03
FUNCTIONALLY AUSTERE TCO	1.01
MANUAL	1.00

Notice the values are not drastically different from those in table 2. These results indicate that automating the C^2 system is a relatively cost-effective way of improving the force. Because the loss ratios among many of the automated systems are relatively close, a conclusive ranking of systems based on this measure of effectiveness is not possible. However, due to the large scale force improvement represented in this measure, the differences between the manual system and some of the automated systems is significant. Furthermore, there is some indication that the decision aids are valuable assets.

The last conclusion drawn from this portion of the analysis is that the value of automation at the lower echelons is relatively small. This is because the cost of providing equipment to these echelons is much higher than the increased performance gained by the additional equipment. Perhaps a less expensive form of automation at these echelons would prove cost-effective.

It should be pointed out that we do not view the procurement of additional tanks as an actual alternative to TCO. If the Marine Corps decides to cancel the program or procure a less costly version of TCO, it is unclear as to how the additional money would be spent. The purpose of the equal-cost analysis is simply to compare the alternatives fairly.

CONCLUSIONS

Based on our analysis, we conclude that automated assistance to the command and control process is advantageous at all three levels of effectiveness. The automated systems demonstrate a clear advantage over the manual system in performance as measured by timeliness and accuracy and assistance from decision aids. This improved performance leads to more accurate perceptions, which, in turn, leads to better allocations of resources. Finally, the equal-cost forces equipped with automated systems do better in battle, as measured by our model, than those equipped with the manual system.

Although automation appears to provide a tremendous opportunity to improve tactical command and control, one must be careful in implementing new systems. Recent events have shown that the development of systems designed to initially automate most C^2 tasks have failed while those that are being implemented in stages have succeeded. Based on an evolutionary strategy, our analysis has shown that the value of decision aids is high and should be given priority for early implementation. On the other hand, the value of automation at the lower echelons is relatively low and alternatives should be examined.

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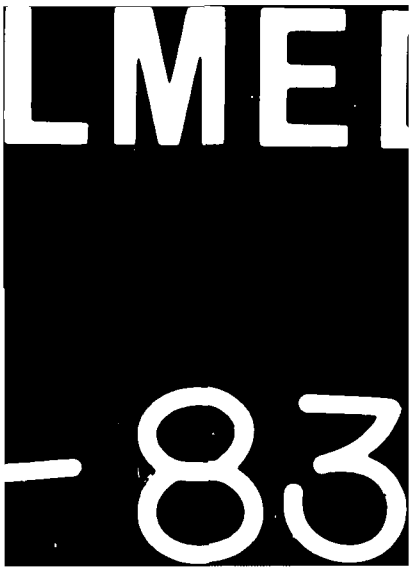
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